Dynamics of Boundary Currents and Marginal Seas

William E. Johns
Meteorology and Physical Oceanography
Rosenstiel School of Marine and Atmospheric Science
University of Miami
4600 Rickenbacker Causeway Miami, Florida 33149-1098
Telephone (voice): (305)361-4054 Telephone (fax): (305)361-4696
Internet address: wjohns@rsmas.miami.edu

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LONG TERM GOALS

To describe and understand the dynamics of ocean circulation, with emphasis on western boundary current systems and interactions between the oceans and marginal seas.

OBJECTIVES

Research during the past year has been focused on studies of the exchange between the northwestern Indian Ocean and its bordering marginal seas: the Red Sea and the Arabian (Persian) Gulf. Measurements of the exchange through the Bab el Mandeb strait, at the entrance to the Red Sea, were collected in 1994-1995, and similar data were collected in the in the Strait of Hormuz in 1996-1997. Our objectives in these programs are to determine the mass, heat, and freshwater fluxes through the straits, and to describe and model the exchanges through the straits and their dominant forcing mechanisms on seasonal to synoptic time scales.

APPROACH

Measurements collected in these programs consist of moored time series observations of currents using profiling (ADCP) and conventional current meters, and water properties using temperature/salinity chain arrays, complemented by seasonal hydrographic surveys and local meteorological and tide gauge measurements. Modeling of the exchange dynamics includes application both analytical models for study of atmospherically forced fluctuations in the straits and numerical models (MICOM) to study the combined buoyancy and wind forced circulations and exchanges within the marginal seas.

WORK COMPLETED

The Bab el Mandeb project has resulted in three published journal articles (Murray and Johns, 1997; Pratt *et al*., 1999, 2000) that describe the observed exchange structure and its hydraulics. Several other papers are submitted or in final stages of preparation:

(1) an analysis of the net heat and freshwater fluxes through the strait and comparison to available surface flux climatologies for the Red Sea (Sofianos *et al*., 2000),

(2) analysis of the energetic short-term transport fluctuations observed in the strait and their relationship to atmospheric forcing, including development of an analytical model to explain them (Johns *et al*., 2000), and

(3) a note on the seasonal sea level fluctuations in the Red Sea as observed by T/P altimeter (Sofianos and Johns, 2000).

Two additional manuscripts from the Ph.D. dissertation of S. Sofianos, completed in June 2000, describe results from MICOM simulations of the Red Sea. These manuscript focus, respectively, on the interior 3-D circulation of the Red Sea and the forcing mechanisms that drive the seasonally varying exchange with the Indian Ocean.

Analysis of the Strait of Hormuz data has resulted in new estimates of the seasonal exchange between the Arabian Gulf and the Indian Ocean (Johns *et al*., 2000) and of the annual mean heat and evaporative fluxes over the Gulf (Smeed *et al.*, 2000). Study of the shorter-term flow and watermass variations in the strait is proceeding. In addition to project related research, an ONR-supported workshop was convened at the Stennis Space Center in May 1999 on the topic of the "Arabian Marginal Seas and Gulfs", whose final report was published in March 2000 and may be found at "http://mpo.rsmas.miami.edu/~zantopp/AMSG-report.html". A manuscript in a related work area, describing new observations and modeling results on the Atlantic inflow to the Caribbean Sea, in collaboration with NRL/Stennis colleagues, was also submitted for publication (Johns *et al*., 2000).

RESULTS

Principal results from the Bab el Mandeb Experiment include:

(1) The annual mean outflow of Red Sea water was determined to be 0.37 Sv, with a large seasonal variation ranging from more than 0.6 Sv in winter to nearly zero in late summer.

(2) Calculation of the heat and freshwater fluxes through the strait leads to an estimate of 2.1 m/yr for the mean evaporation rate over the Red Sea, and 10 W/m2 for the net annual heat loss over the Red Sea. These new estimates confirm the existence of large biases in available climatological surface fluxes (e.g., COADS) for the Red Sea.

(3) Synoptic transport variations in the strait on time scales from a few days to weeks is driven by two primary forcing mechanisms: wind stress variability over the strait, and variation in the large-scale barometric pressure over the Red Sea. These transport variations have amplitudes of nearly twice the mean rate of exchange through the strait, and can be accurately modeled by a linear 2-layer frictional model that accounts for the Helmholtz resonance of the basin.

(4) Numerical simulations of the Red Sea using of the Miami Isopycnal model are able to reproduce the observed annual cycle of the exchange, and show that this variation is mostly produced by the wind forcing, while the seasonal buoyancy forcing plays a secondary role. However, the model shows that inclusion of the large annual cycle of buoyancy forcing over the Red Sea is necessary to accurately model the annual mean exchange rate with the Indian Ocean.

Results from the Strait of Hormuz Experiment include:

(1) The deep outflow from the Persian Gulf does not show a strong annual variation. However, its speed and salinity vary considerably on shorter time scales, with pulse-like events of high salinity outflow occurring during the winter months.

(2) The surface inflow layer shows a significant variation on seasonal as well as shorter time scales, and a mean outflow occurs in the southern part of the Strait during boreal fall and winter. The total exchange through the Strait thus appears to involve a seasonally active horizontal water exchange in addition to the more steady two-layer thermohaline exchange.

(3) The magnitude of the annual mean deep outflow of Persian Gulf water through the Strait is estimated to be 0.21 Sv, implying a net evaporation rate over the Gulf of 2.0 m/yr. As for the Red Sea, the heat flux through the strait estimated from these direct measurements implies a significant positive bias in the surface heat flux input to the Persian Gulf in most available flux climatologies.

IMPACT/APPLICATIONS

These observational programs have provided the first detailed, long-term measurements in these critical straits, and should yield a new level of understanding of the relevant exchange processes and their dynamics. Comparative studies with other marginal sea straits (e.g., Gibraltar) will help to improve and broaden our understanding of the dynamical controls regulating ocean-marginal sea exchange. The heat and freshwater transports determined from these measurements will provide powerful constraints on air-sea fluxes in these regions to help eliminate biases in existing flux climatologies.

TRANSITIONS

The data and results from these projects are being provided to the Naval Research Lab and Naval Oceanographic Office data and modeling groups to provide accurate boundary conditions for their Red Sea and Persian Gulf models and for coupling of these models to Indian Ocean models.

RELATED PROJECTS

Analysis of the Strait of Hormuz moored time series data is being carried out in collaboration with U.K. investigators David Smeed and Simon Josey of the Southampton Oceanography Centre, who performed extensive shipboard surveys in the strait region during the period of the moored deployments and are developing and evaluating surface flux climatologies for the region. A collaboration has also been established with Dr. Amy Bower of Woods Hole to investigate the hydrography and circulation in the Arabian Gulf in relation to the Strait of Hormuz exchange, and the characteristics of the outflow plume from the Gulf.

PUBLICATIONS

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